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WITH HOLLOW CIRCULAR WAVEGUIDE IN CAVITY

by

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PULSED TUNABLE NARROW-BANDWIDTH DYE LASER WITH HOLLOW CIRCULAR WAVEGUIDE IN CAVITY

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Abstract

This paper presents a novel widely tunable, pulsed dye laser with single transverse mode narrow bandwidth which can be constructed by using a grazing-incidence grating in conjuction with a hollow circular dielectric waveguide. The experimental results show that the single transverse mode narrow bandwidth laser output can be obtained while maintaining a high lasing efficiency. The mechanism of the improvement is also discussed in this paper.

Key words: hollow circular dielectric waveguide, grazing-incidence grating; narrow bandwidth pulsed dye laser.

Since the narrow-frequency-band pulsed tunable dye lasers are extensively applied in the fields of physics, chemistry, and biology, researchers continuously study various methods of controlling the output mode of the pulsed dye lasers in order to attain high-quality oscillation output of narrow-frequency-band lasers [1, 3]. This article reports on a new design: a circular hollow waveguide is inserted into a conventional Littman resonant

cavity [4]. As revealed in measurement results of experiments, by comparing with conventional Littman resonant cavities, there have been great improvements on output parameters of energy, mode, and frequency bandwidth in the output of the laser system.

I. Design Concepts

For a conventional Littman resonant cavity structure, the following relationships are obtained:

$$\Delta\lambda = \frac{2\sqrt{2}\lambda}{\pi L m} a, \quad \frac{L\cos\theta}{2d} = \frac{\lambda}{\pi\omega}, \tag{1}$$

In the equation $\Delta\lambda$ is the laser output frequency bandwidth of the cavity; ω is the radius at the waist of the light beam; d is the distance between the grazing-incidence grating center to the dipole. From Eq. (1), in the conditions that the grating constant a, diffraction order number m, and wavelength λ are deterministic, the laser output frequency band will be narrowed if increasing the illumination width (L) of the grating is increased. However, to attain large L, $\cos\theta$ should approach 0. In other words, the grating incidence angle θ approaches 90°. Then the diffraction wear in the laser cavity will be greatly increased. As shown in Fig. 1, the frequency bandwidth of the system spectrum is

$$\Delta\lambda = [(\Delta\lambda_{\lambda})^2 + (\Delta\lambda_{\text{出}})^2]^{1/2} = \left[\left(\frac{\partial\lambda}{\partial\theta_1}\right)^2 (\Delta\theta_1)^2 + \left(\frac{\partial\lambda}{\partial\theta_2}\right)^2 (\Delta\theta_2)^2\right]^{1/2}, \tag{2}$$

In the equation, $(\partial\lambda/\partial\theta)$ is the angular chromatic dispersion; $\Delta\theta$ is the variation value of the incidence angle or exit angle of

a light beam. From Eq. (3), if a method can upgrade the collimation effect in a Littman cavity, the laser output frequency band can be narrowed. Moreover, shortcomings in the conventional Littman cavity can be overcome. In other words, narrowing the laser output frequency band has the penalty of increasing diffraction wear in the cavity. In [6, 7], a cylindrical surface focusing lens or a beam expander system was inserted in the cavity to collimate the light beam, thus achieving the purpose of narrowing the output beam frequency band. Although these methods are effective, still they increase the absorptiuon wear in the cavity, and have other disadvantages of not being easily adjustable and being unable to attain the fundamental mode output.

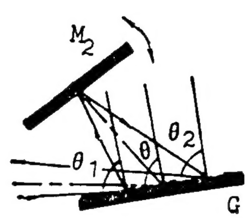

Fig. 1 Detail of the optical path between a grazing-incidence grating G and a tuning fully reflecting mirror $M2$

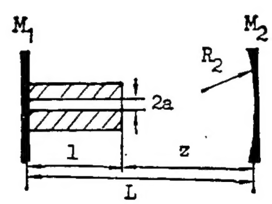

Fig. 2 A hollow circular dielectric waveguide laser cavity

As shown in Fig. 2, for the hollow circular waveguide resonant cavity, a set of orthogonal normalized vectors can be used to indicate the intrinsic mode function of the waveguide inside the cavity, that is,

$$TV = AV \quad (3)$$

In the equation, T is the complex transfer matrix for one reciprocating motion in the cavity; A is its intrinsic value. For the first time, the authors applied the matix nondiagonal analytical method in their calculations, thus indicating the following [8]: after an appropriate circular hollow waveguide was imserted into the laser cavity, it was discovered that functions of the control mode and collimation light beam exist in the resonant cavity. Moreover, in the resonant cavity high-order-mode energy was coupled to become low-order-mode energy. Thus, the fundamental mode laser oscillation output in this resonant cavity can be greatly increased.

II. Experimental Technique

In the experiments, the pumping source of the pulsed dye laser employs a double-frequency light (λ = 532nm) of a tunable Q Nd :YAG laser with 10ns as the pulse duration, 4.2 to 6.4mJ as the output energy, and 1Hz as the pulsed frequency. Fig. 3 shows the structure of the laser cavity with a hollow circular waveguide. The concentration of rhodamine 6G is 2.9×10^{-4} mole; the graduation lines of grating G are 1800 lines per mm; the flash wavelength is 600micrometers; and the width is 40mm. For the output length M_1, the transmissivity is 60 percent in the range between 500 and 620nm. The tunable resonant length M_2 is the total-reflection mirror. The length of the laser cavity is 200mm. In the experimental process, different sizes of hollow circular waveguides were used. It was found that a hollow

circular waveguide of 80mm in length and 0.6mm aperture is most suitable for the requirements of this experiment. If the aperture of the waveguide tube is too small, the intra-cavity diffraction loss is greater. However, if the aperture of the waveguide tube selected is too large, the effect of limiting the transverse mode and straightening the light beam can be attained. Therefore, for a pulsed dye laser with different structures and increment of the resonance oscillator cavity, hollow circular waveguides with different aperture and length should be selected in order to attain the optimal effect of limiting the transverse mode and straightening the light beam. The adjustment steps of a Littman cavity with a hollow circular waveguide are as follows:

(1) By using an output lens M_1 and a total-reflection mirror M_2 to constitute a flat-flat laser cavity, make adjustments so that the outputted laser attains the highest power. (2) Insert a hollow circular waveguide with 0.6mm as the aperture and 80mm as its length into the cavity nearing the output lens M_1, carefully adjust waveguide 2 so that not only is the laser output energy at a maximum, and at the same time the outputted laser should be a bright light spot at the far field. (3) Remove the reflection mirror M_2 at the side in the absence of the waveguide tube, then according to Fig. 3, place the grating G and tunable total-reflection mirror M_2. Adjust G and M_2 so that the laser is outputted as a bright light spot at the far field. Used in the experiment, a plane Fabry-Perot standard device is to analyze the frequency band of the outputted laser. Use a camera to record

the interference fringes on the focal plane of the Fabry-Perot standard device. Then use an automatic recording and scanning blackbody detector to record and analyze.

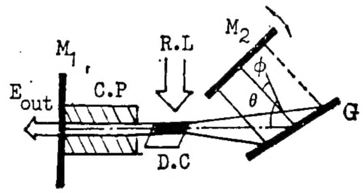

Fig. 3 Schematic diagram of the Littman cavity with hollow circular dielectric waveguide
C. P.—a hollow circular dielectric waveguide of length =80 mm and internal diameter=0.6 mm

III. Experimental Results and Discussion

By using the conventional Littman cavity (taking the hollow circular waveguide C.P. in Fig. 3), only when $\theta \geqslant 85°18'$, there appear the interference fringes with alternating bright and dark bands on the focal plane of the plane Fabry-Perot standard device. In addition, measurements showed that the frequency band of the laser output was 12GHz (as shown in Fig. 4) when $\theta = 87°20'$. However, by using the Littman cavity with intracavity hollow circular waveguide (Fig. 3), when $\theta \geqslant 69°5'$, interference fringes with alternating bright and dark bands appear on the focal plane of the Fabry-Perot standard device. Moreover, measurements showed that the laser output frequency band width was 2GHz (as shown in Fig. 5) when $\theta = 85°37'$. The free spectral region was 20GHz for the plane Fabry-Perot device used in this experiment. The discrimination limit is approximately 2GHz. Therefore, with

respect to the Littman resonant oscillator cavity with intra-cavity waveguide, the laser frequency bandwidth outputted from the cavity is certainly smaller than 2GHz only when the grazing-incidence angle $\theta > 85°37'$.

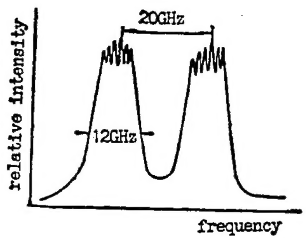

Fig. 4 Characteristic of laser output linewidth for a basic Littman cavity at the grazing incidence angle $\theta = 87°20'$

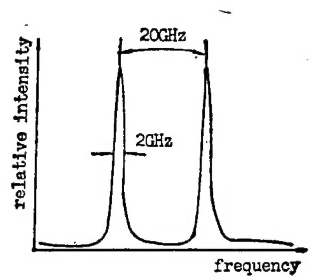

Fig. 5 Characteristic of laser output linewidth for a Littman cavity with a hollow circular dielectric waveguide at the grazing incidence angle $\theta = 85°37'$

(2) In the experiments, it was found that the laser output lightspot from the Littman cavity with intra-cavity hollow circular waveguide is a bright circular point; in other words, the laser output mode from the cavity is a single transverse-mode as shown in Fig. 6. In the case when the grating incidence angle θ varies within the range $60° \rightarrow 89°$, the output energy E_{out} from the pulsed dye laser varies within the range $1.12\,mJ \sim 290\,\mu J$. Generally, the laser output lightspot from a Littman cavity is not a bright circular point in the far field; that is, the laser output mode is a higher order transverse mode, as shown in Fig. 7. in the case when the grating incidence angle θ varies within the range $60° \rightarrow 89°$, the output energy E_{out} from this pulsed dye laser varies within the range $720\,\mu J \sim 44\,\mu J$.

Fig. 6 The far-field pattern of dye laser for a Littman cavity with hollow circular dielectric waveguide

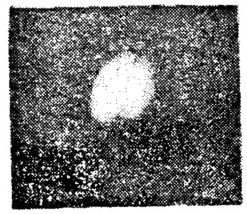

Fig. 7 The far-field pattern of dye laser for a basic Littman cavity

By comparing the measurement results in the experiments mentioned above, after inserting a hollow circular waveguide (with 0.6mm as the aperture and 80mm as the length) into a conventional Littman cavity, the output parameters of the pulsed dye laser are greatly improved, mainly shown as follows: for cases with the same grating incidence angle θ, a comparison of the Littman cavity with an intra-cavity hollow circular waveguide and a conventional Littman cavity shows that the former cavity can apparently have a higher laser energy output and can obtain a narrower laser output waveband than the latter cavity; in addition, the output mode of the former is also better. In the authors' view, the reasons for the improvements in these parameters are as follows: (i) after inserting an appropriate hollow circular waveguide into the conventional Littman cavity, since the laser oscillation mode in the resonant oscillation cavity changes into a single transverse mode from the previous higher-order transverse mode, therefore the straightening effect of intra-cavity light beam propagation is much greater. In this

case, the angular chromatic dispersions of the incident and the emergent light of the grating G in Fig. 1 become much smaller. In other words, the two quantities $(\partial\lambda/\partial\theta_1)^2(\Delta\theta_1)^2$ and $(\partial\lambda/\partial\theta_2)^2(\Delta\theta)^2$ in Eq. (3) are apparently smaller. As a result, in the case of a definite grating incident angle θ, because of the presence of the intra-cavity hollow circular waveguide, the laser output frequency band is obviously narrower. (ii) Since besides selection and control of the intra-cavity laser oscillation due to the hollow circular waveguide in the cavity, the laser energy of the higher-order transverse mode in the cavity can be coupled into laser energy of a lower-order transverse mode. The results show that after the hollow circular waveguide is inserted into the cavity, the laser output energy is not reduced as in the case when a small-hole diaphragm restricting the transverse mode is inserted into a conventional cavity, and the output energy even increases. The experimental results of the mutual coupling function between modes for a hollow circular waveguide in the resonant oscillator cavity are the same as those reported in reference [9,10].

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